The Role of Magnetic Field in Atomic Layer Deposition of Al_2O_3 Thin Films Enhanced by Radio Frequency Plasma

Qiang Chen, Xincun Li, Wenwen Lei, Lijun Sang, Lizhen Yang, Zhenduo Wang and Zhongwei Liu

Laboratory of Plasma Physics and Materials, Beijing Institute of Graphic Communication, 102600, Beijing, China

Abstract: As a media aluminum oxide (Al_2O_3) thin films deposited by radio frequency plasma-assisted atomic layer deposition (RF-PA-ALD) method were employed to explore the magnetic field effect. Different from normal plasma-assisted ALD (PA-ALD) technology a magnetic field was applied during the whole deposition process. With this novel ALD technology it obtains that the deposition rate in each cycle of ALD is significantly improved. Moreover an ultra-flatness surface, roughness in 0.06 root mass square, was formed in this novel ALD technology. Based on in-situ diagnostic we assume a new mode for Al_2O_3 growth in the magnetized plasma assisted ALD.

Key words: magnetic field, plasma assisted atomic layer deposition, Al_2O_3

Introduction

Aluminum (Al_2O_3) is an appropriate material used as alternative inactive dielectrics [1, 2] , protective coatings[3, 4] and moisture permeation barriers[5, 6] due to its excellent physical and chemical predominance [7], such as a high dielectric constant (~9), a large band gap (8.7 eV), a high field strength (6~ 8 MV/cm) and stability again the chemical and thermal [8, 9].

Many methods were employed to prepare Al_2O_3 thin films, including magnetron sputtering [10], plasma enhanced chemical vapor deposition (PECVD) [11], and atomic layer deposition (ALD) [12]. Due to ALD technology, one of the CVD methods, can deposit ultra-thin films with a perfect self-limiting, a good conformlity and a super high aspect ratio [13-15], this technology is widely utilized in transistor gate dielectric formations in microelectronic industry in recent years [16-18]. However, the reported thermal ALD methods were limited by like the narrow window of growth temperature, much slow deposition rate, and few chosen precursors and so on. With plasma assisted, it seems thermal ALD can be improved and processed in low temperature with a relatively high deposition rate [19]. But the etching, radicals transferring in linear in PA-ALD technology lead to the film with a high roughness surface and a poor conformlity.

In this paper, we used a magnetic field to confine the reactive species in radio frequency (RF) PE-ALD. The purpose in the work is to improve the quality of thin film deposited by the PA-ALD technology, especially the film growth rate and surface smoothness.
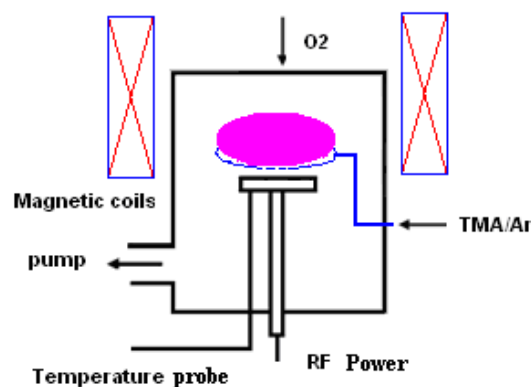
Experiments

Figure 1 The schematic diagram of magnetic enhanced PE-ALD system

Fig. 1 is the schemtical diagram of home-made RF-PE-ALD. In the experiment, Al_2O_3 thin films

deposited on polished p-Si (0.05 nm in smoothness) were used as media to explore the role of magnetic field, where trimethylaluminum (TMA) and O_2 were employed as precursor and oxidant, respectively. The confinement magnetic field is generated by several magnetic field coils, which were amounted just over the RF electrode as Fig. 1 shows. The magnetic field strengths on the substrate surface were tunable from 0 mT, 1.7 mT, 3.5 mT, to 5.0 mT to explore the influence of magnetic field on Al_2O_3 growth rate and surface smoothness. The processing parameters in whole processing were that RF power was fixed at 100 W, the working pressure was around 0.2 Pa, Ar as the carrier and purge gas was flowing at 20 sccm and at 30 sccm, respectively, and O_2 was at 15sccm. The cycled periods were that TMA purging for 4s, Ar purging for 20s, then O_2 pulse plasma discharge for 10s, and at last Ar purging for 20s.

Results and discussion

The growth rate of ALD- Al_2O_3 was measured by Dektec 150 profilemeter (Vecco). Fig. 2(a) shows the relationship of the film thickness with the number of cycles on polished Si substrate. One can see clearly that the growth rate is in linear with the deposition cycles, which means the Al_2O_3 thin films is grown at layer by layer in ALD mode. Especially as is demonstrated that the growth rate was ca. 0.35 nm/cycle in magnetized RF-PA-ALD, which is very much higher than that growth in thermal ALD (0.08 nm/cycle for thermal ALD in H_2O vapor; 0.06 nm/cycle in thermal ALD in O_3 vapor), or RF-PA- ALD (0.14nm/cycle in inductively coupled plasma (ICP) enhanced ALD with O_2 as oxide) [20]. It means the magnetized RF-PA-ALD can significantly improve the ALD deposition rate.
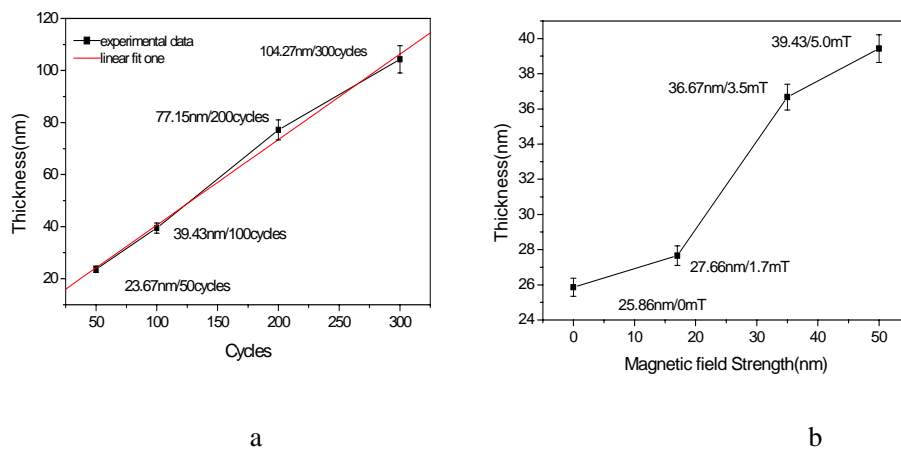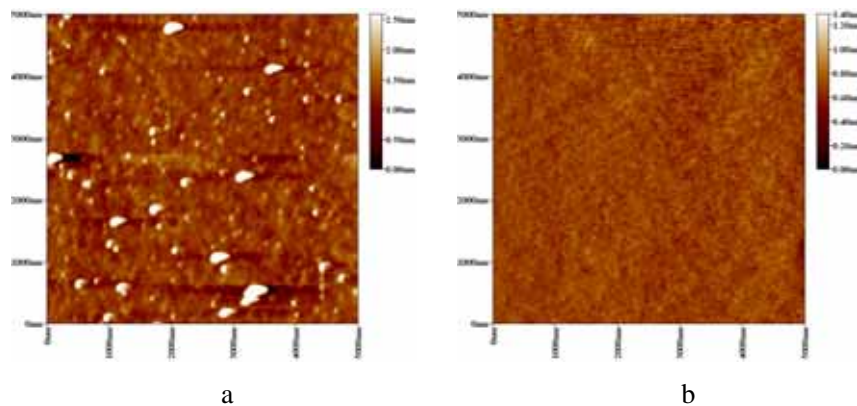

a   b

Figure 2 a-as-deposited film thickness versus the depostion cycle (50, 100, 200 and 300 cycles); b-the influence of magnetic field strength on as-deposited film thickness (100 cycles)

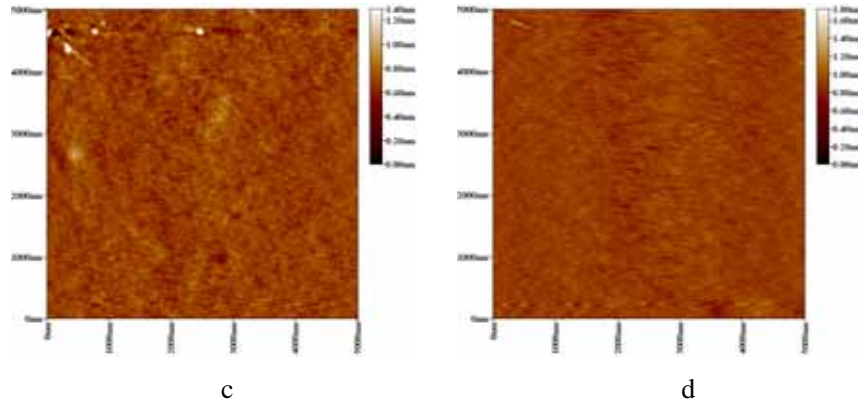a   b

c   d

Figure 3 The influence of the magnetic field strength on the surface roughness. a-0 mT/0.35 nm; b-1.7 mT /0.237 nm; c-3.5 mT/0.067 nm; d-5.0 mT/0.069 nm

Confirmedly, the film growth rate strongly depending on the magnetic field strength was carried out by varying the magnetic filed strength on the substrate surfaces. Fig. 2(b) shows that the growth rate was 0.26 nm, 0.28 nm, 0.37 nm, and 0.39 nm/cycle when the magnetic field strength was at 0 mT, 1.7mT, 3.5mT and 5.0mT, respectively. It attains the magnetic field indeed takes a positive role in the improvement of the film growth rate.

With the atomic force microgram (AFM), Fig. 3 reveals that the morphologies of as-deposited films also significantly depend on the magnetic field strengths. From these images one can see that the Al_2O_3 thin films deposited in magnetized PA-ALD are excellent conformlity, uniformity and smoothness. The root mean square (RMS) roughness of the as-deposited film is 0.53 nm at 0 mT,   whereas it become smoother and smoother along with the increase of magnetic field strengths. The RMS is 0.237 nm at 1.7mT, 0.067 nm at 3.5 mT, and 0.069 nm at 5.0 mT, which are remarkably smaller than those deposited by chemical vapour deposition (CVD, 0.5-2 nm) [21], molecular beam epitaxy (MBE, 0.3-5 nm) [22] and thermal ALD (0.3-1 nm) [23]. The roughness of RMS is near equal to the polished p-Si (100) surface (0.05 nm in RMS).

These results imply that the magnetic field confinement might be very valuable method for the improvement of conformlity, uniformity and smoothness in PA-ALD.

Bases on the result we definitely consider that chemical absorption mechanism in thermal ALD is not available in magnetized PE ALD. With the in-situ diagnostic of optical emission spectroscopy and mass spectroscope, the super-flatness thin film growth mechanism is considered as the combination of O radical-driven combustionlike reactions with the active radical surface absorption reactions in magnetized PA-ALD.

Conclusions

In this paper, we report a novel ALD technology, the magnetized plasma assisted ALD, in which a high rate and super-flatness thin films can be achieved. It obtains that the magnetic field strength significantly influenced the deposition rate and morphology, the higher magnetic field strength, the higher deposition rate and the smoother surface.

Acknowledgments

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